Techno economic analysis of SPV-DG hybrid model using HOMER

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Abstract-

This study conducts a comprehensive Techno-Economic Analysis of the Solar Photovoltaic (SPV) - Diesel Generator (DG) hybrid energy system model implemented in Leh, a high-altitude region in India. The integration of renewable energy sources with conventional generators has gained significance in remote areas, where grid connectivity is challenging. The HOMER software is employed as a tool for the optimization and simulation of the SPV-DG hybrid system. The research focuses on assessing the technical feasibility and economic viability of the SPV-DG model in Leh, considering the unique climatic and geographical conditions of the region. The simulation results are analyzed to determine the optimal sizing of the SPV and DG components, as well as the overall system performance. The techno-economic evaluation includes a life cycle cost analysis, considering capital costs, operating and maintenance expenses, and fuel costs. The study also explores the environmental impact of the SPV-DG system, emphasizing the reduction in greenhouse gas emissions and dependence on fossil fuels.

INTRODUCTION

Energy is irreplacable. It is a basic need for life. The cutting edge society burns-through more than the past age because of obvious reasons. Examples of energy use will soon be more severe [1]. Energy is estimated in different units according to the estimated quantity [2]. To achieve climate goals, low-carbon energy technologies, such as solar power, need to be prioritized and deployed at scale. India has done an outstanding job in implementing renewable energy installations. As of March 31, 2021, the total installed solar capacity is 40.1 GW and the Indian government has stated its ambition to increase solar capacity to 100 GW by 2022 (Status, Energy). solar energy, Ministry of New and Renewable Energy (MNRE), Government of India, n.d.) [3].

Diesel generators are one of the project's supply sources. Diesel generators are capable of generating electricity in any situation, regardless of weather conditions. However, the use of diesel generators will certainly cause environmental pollution, which is a matter of real concern for research. However, the goal in this regard is clear: diesel generators will only be used in emergencies and when the combined operation of solar PV and batteries does not allow to satisfy the load. This usage mode not only improves system reliability but also reduces pollution. Medical facilities can also benefit from uninterruptible power. The combined operation of solar photovoltaic and diesel engine can effectively respond to the load.

Designing a Solar Photovoltaic (SPV) - Diesel Generator (DG) hybrid model in Leh presents a distinctive challenge and opportunity due to the region's high altitude, harsh climate, and seasonal variations. The design must intricately balance the intermittent nature of solar power with the reliability of diesel generators while considering the logistical challenges associated with fuel transport in remote areas. Leveraging the abundant solar radiation unique to Leh's geographical location, the system should be optimized to minimize diesel consumption, ensuring sustainability and reduced environmental impact. Additionally, the design needs to account for the specific load demand characteristics of the local community, engage in community participation, and integrate efficient energy storage solutions to provide a reliable and resilient power supply tailored to Leh's unique energy landscape.

LITERATURE REVIEW

Panicker et al (2023), stated that Building Applied Photovoltaics (BAPV) such as Roof-top Solar PV has attracted substantial attention in recent years for tapping the untapped potential of renewable energy sources. However, in tightly packed urban residential zones, rooftop PV presents challenges due to space constraints and shadowing. The purpose of this research is to develop and evaluate the feasibility of an integrated grid-connected Rooftop and Façade Building Integrated Photovoltaic (BIPV) system for addressing the energy demands of residential buildings on an academic campus [4]. Bhavani et.al(2023) investigated the influence of PV change in solar temperature and irradiance on various conditions and inverter output in a grid-connected system. The simulation-based study was conducted to analyze the fluctuation of inverter output with the variation of solar temperature and irradiance with climatic variation [5]. Agarwal et.al(2022), presented that photovoltaic (PV) technology confronts a significant land need. This paper performs simulation tasks to examine the technical potential of floating photovoltaic power generation and addresses the sustainable system of floating solar PV technology in terms of anticipated PV potential, water conservation, and the potential to protect agricultural land bank [6]. Muskan et.al(2023), presented that conventional energy resources include coal, petroleum, natural gas, and other fossil fuels. . Using HOMER Software, this study analyzes the feasibility of a PV and diesel generator-based system suitable for the Akhnoor town in the Jammu district of Jammu and Kashmir, India. The optimal option, according to the optimization findings, is to employ components with an NPC of $16,157. PV arrays of 1.98 kW are employed, and a generator of 1.40 kW is required for the proposed system [7]. Kumar et al. (2021) investigate the techno-economic performance of a hybrid solar photovoltaic (SPV)/diesel generator (DG) system using four different battery energy storage (BES) technologies. The work analyzed performance characteristics like as system cost, return on investment, simple payback period, energy generated, pollutant emissions, renewable penetration, and so on [8]. Quadri et al. (2019) evaluated the importance of RES-based power generation system analysis due to its fluctuating nature. The primary goal of this endeavor is to supply continuous electrical power to rural regions where grid electricity is not accessible full-time or is not electrified in order to fulfill the Government of India's vision of "Power to All" by 2020 [9].

METHDOLOGY USED

The Hybrid Optimized Model for Electric Renewables (HOMER) [10], a simulation technology based on renewable energy developed by the National Renewable Energy Laboratory (NREL) of the United States, used for simulation in the study. The software is widely used in many countries to simulate the model to determine the feasibility and feasibility of the model before deployment. The software can simulate different renewable and non-renewable sources and can manage the time step to get simulation with desired duration. The software iterates the given combinations to find the optimal combination, the sensitivity analysis ensures project safety. The software has many outstanding advantages. The simulation offers many variations, especially the financial variant, which makes the program more attractive [11].

SOLAR ENERGY RESOURCE

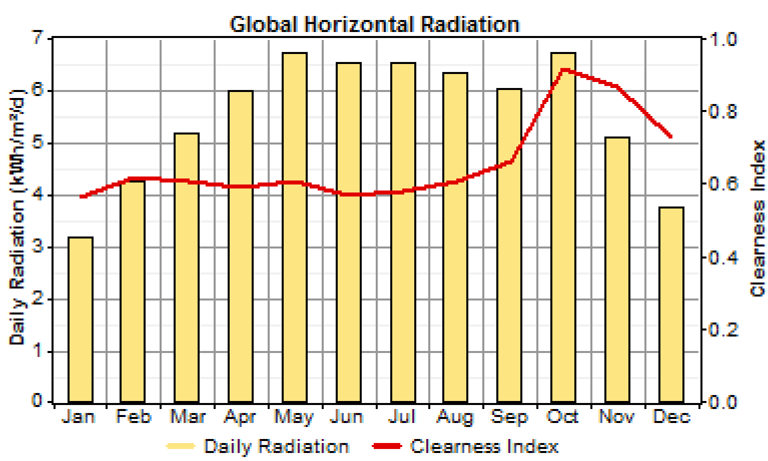

Fig. 1 Solar resource available on site

For the proposed scheme, solar-based energy makes up a huge part. With the new invention, the solar power use is becoming obvious. The generation of energy from a PV array depends on the environmental conditions in which it is presented. The normal range of controlled solar radiation in India is 4-7 kWh/m2/day. The audit was performed at a range of 34.35 degrees and longitude 76.45 degrees. In addition, for the proposed site, irradiance is observed to be 5.48 kWh/m2/day with clearness index of 0.656, the installed capacity of the solar PV is 4 kWP.

DIESEL GENERATOR

Diesel is used as fuel for diesel generators. The amount of diesel used is very small and is very easily available in the nearby market. However, the necessary diesel is purchased and stored for use whenever needed. Since the operation of such a generator is limited, fuel can be stored in the same control station. The installed capacity of the generator in the scheme is 2.5 kW.

DESCRIPTION OF THIS SYSTEM

The proposed scheme consists of a photovoltaic generator and a diesel generator as the main power source and the battery as the secondary source, load and control mechanism. The system is considered to be operating in off-grid mode. The study was designed with a community center in Ladakh where critical loads are located.

The scheme discussed in this study uses two power sources. The solar PV and diesel generator. Solar power is very intermittent, however this feature is managed by integrating a battery bank. Properly optimized battery bank maintains current balance by continuously charging and discharging the battery bank. The charge controller is used to control the battery bank. The power source generates electricity, which supplied to the load and the battery. Diesel generators are used for a very limited time. In addition, the battery bank provides supply in case the PV capacity is lower than the load demand. When the combined operation of the SPV and the battery does not meet the full load, the diesel generator will operate. However, the system finds the integration of such systems successful as more than 98% of the total load can be handled by this combination.

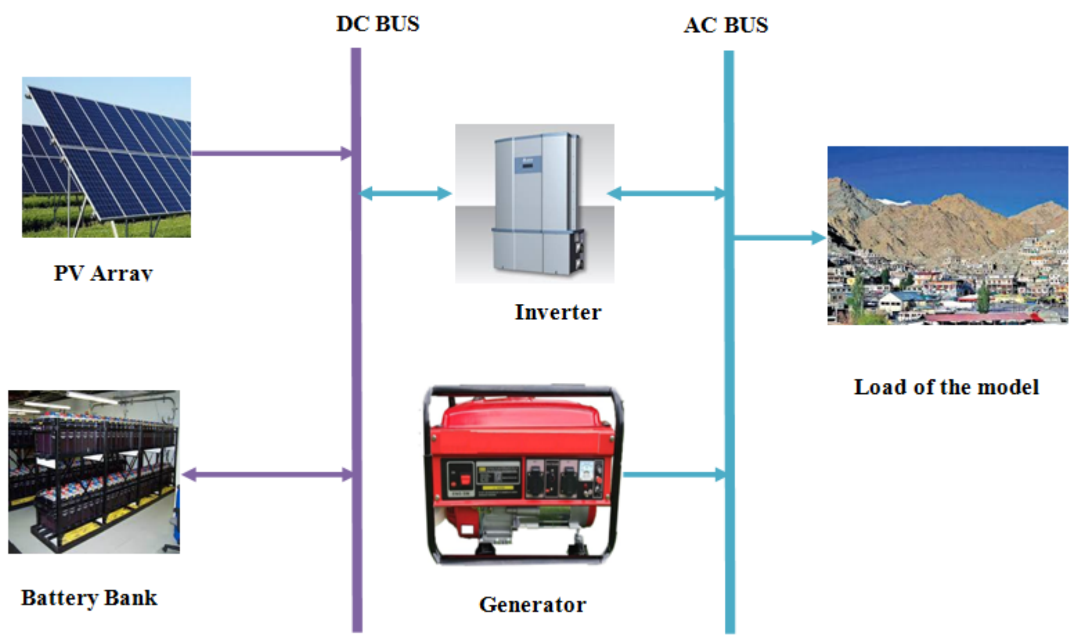

Fig. 2 Proposed Model

RESULT AND ANALYSIS

LOAD PROFILE

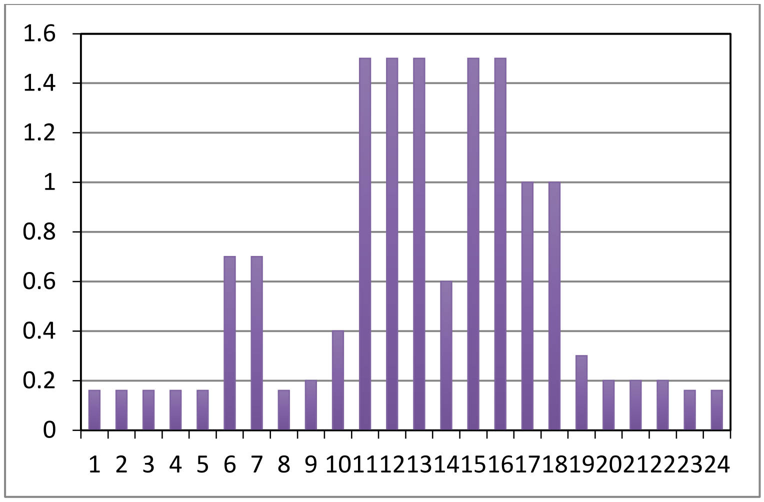

Fig. 3 Hourly load

The proposed model is intended to serve a daily power output of 14 kWh/day with a peak of 2.8 kW. In addition, the demand for energy will increase due to the increasing quantity of critical equipment in the said premises. So, in this study, the typical load created by the equipment is calculated to be 14kWh/day normal and then synthesized into the HOMER schedule adding various days, to create proper load schedule.

SOLAR RADIATION AND OUTPUT POWER

The below figure depicts the power produced by the PV in each month. It is observed that maximum output of 2.16 kWh occurs at an average radiation of at an average radiation of 0.333kW/m2 throughout the day.

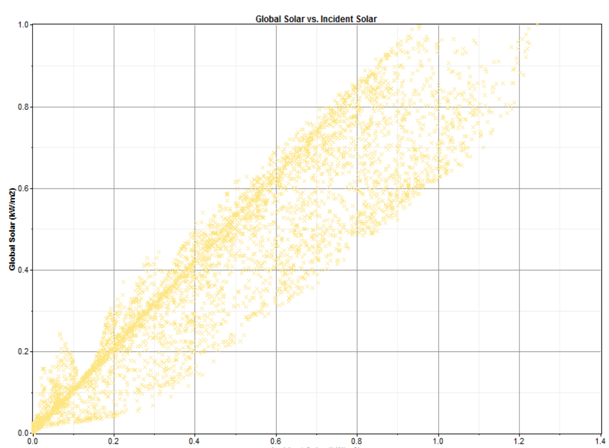

Fig.4 Solar Radiation and PV Output Power

MONTHLY POWER OUTPUT FROM PV ARRAY

The average monthly power output from PV is shown in the below graph. It is observed that throughout the year, PV can generate a suitable amount of energy, highest enenrgy production from the SPV os observed rom Sptember to November. Due to the presence of cloud cover, electricity output varies at the proposed location. Depending on geographicallocation of the site and the installed capcity, the photovoltaic generators are estimated to produce 5,743 kWh of energy per year.

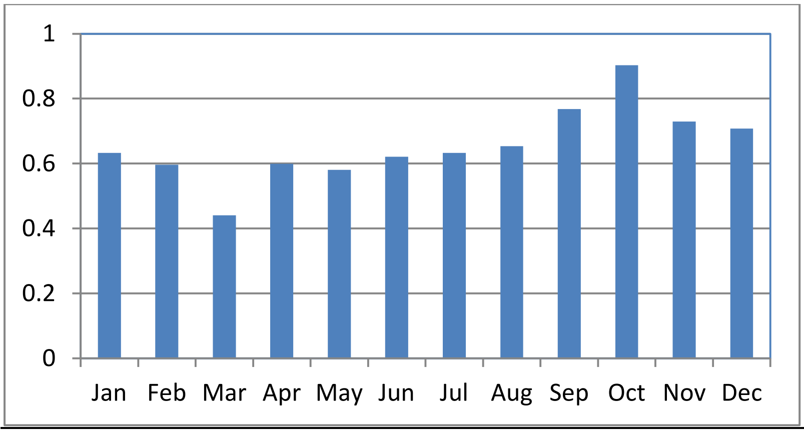

Fig.5 Average power production of PV array

DIESEL GENERATOR OUTPUT

The diesel generator is the power source integrated into the system to improve system reliability. Diesel generator pollutes the environment where it operates. But it is very significant as it is used only in emergencies for the critical installed loads. The output power of diesel generators is very limited and rarely used. The output of diesel generator is 725 kWh per year. But it will be useful to maintain supplies and maintain the installation in difficult weather conditions. Some equipment requires uninterruptible power supply, the diesel generator set ensures these benefits.

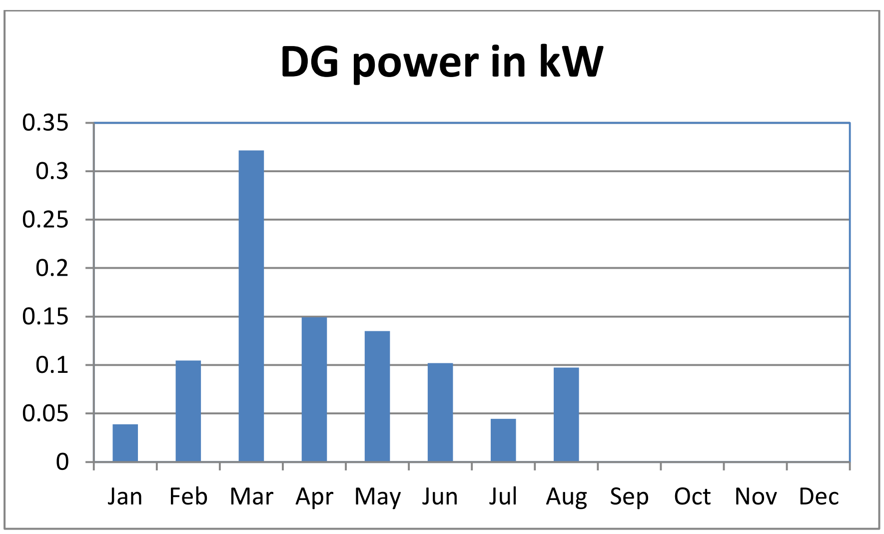

Fig. 6 Diesel generator Output

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BATTERY OUTPUT

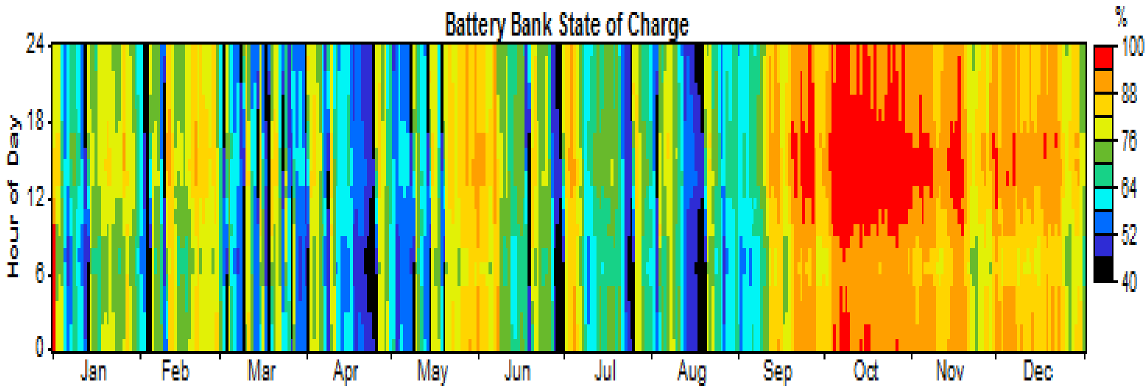

Fig. 7 Battery state of charge

The system used the battery as a secondary power source. And the scheme uses the controller to charge the battery when the remaining power is left after meeting the local charging demand. To improve power quality, simultaneous charging and discharging are considered. The energy throughput of the battery is 2,525 kWh/year. Figure 4.5 shows the variation of SoC by month, it is observed that in the month with a lot of electricity generated from solar, the SoC is also high and in the months with low solar energy, the battery discharges to the optimal level to meet the load.

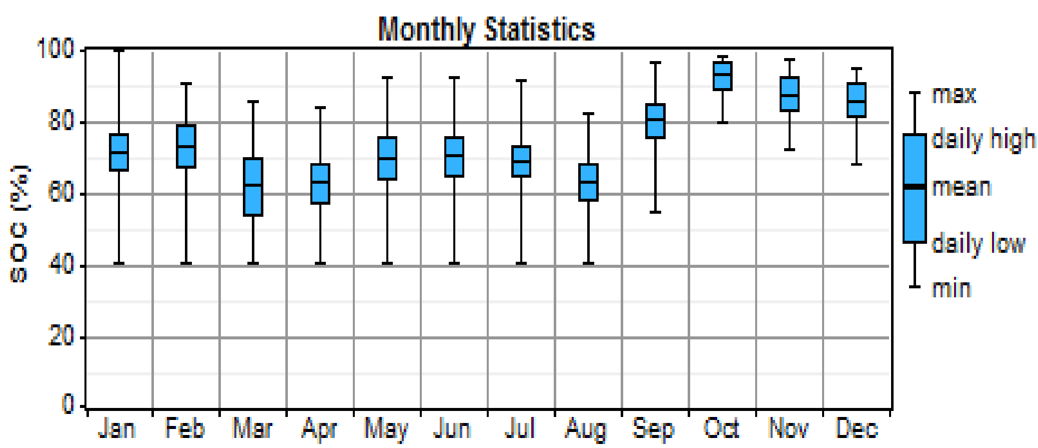

Fig 8 Battery SoC variation

DAILY MEAN ENERGY PRODUCTION AND LOAD DEMAND

The program used photovoltaic solar energy with a diesel generator as the power source. The blue bar shows that solar power generation which dominates the electricity generation, which is also the purpose of the system. The orange bar represents the power output of diesel generator, used only in case of emergency. Such an integration seems to be successful because the entire load demand is met by such a combination. The black line shows the energy need of the proposed model.

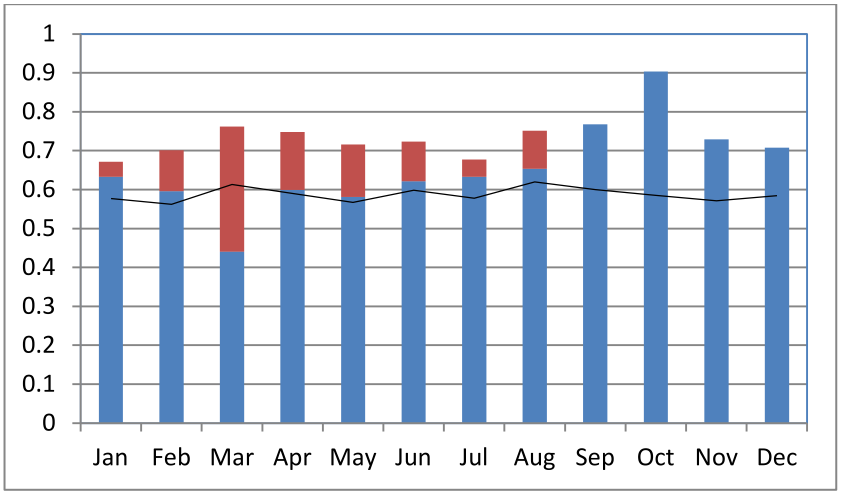

Fig. 9 Daily mean energy production and load demand

POLLUTANT EMISSION FROM THE SYSTEM

The table mentioned below describes the discharge of pollution from the system. However, to reduce pollution levels, diesel generators have been used wisely and only in emergencies. However, this short time also causes some pollution. Although it is negligible and the level of contamination is acceptable as it is only used in an emergency.

Table 4.1 Emission from the system

Pollutants	Emissions (kg/yr)
CO_2	645
CO	1.59
Unburned hydrocarbons	0.176
Particulate matter	0.12
SO_X	1.3
NO_X	14.2

HOURLY ENERGY BALANCE OF THE PROPOSED SYSTEM

The equilibrium of the system explains all the energy produced during the observation period and how the energy is used. The main job of the model is to meet the load 24/24. Proposed load model need more electricity during the day, which is provided mainly by installed PV and partly by diesel generators. The excess amount is used to charge the system and the system calculates that the model requires relatively less power and remains constant for other time periods.

The figure below shows the energy balance. From midnight, the diesel generator runs to serve the load and also to charge the battery. The blue bar only generates solar power during sunny hours. When the solar insolation declines late in the evening, PV generation is turned off. The entire charging process performed by a battery that was charged during the day and the previous night is shown in a yellow bar. It can be observed that during discharging it is displayed above the zero line and during charge it is below the zero line. At all times the energy balance is maintained by the load and the source. The system observation founds that their neither any excess energy remains on the system nor any short fall of energy is recorded.

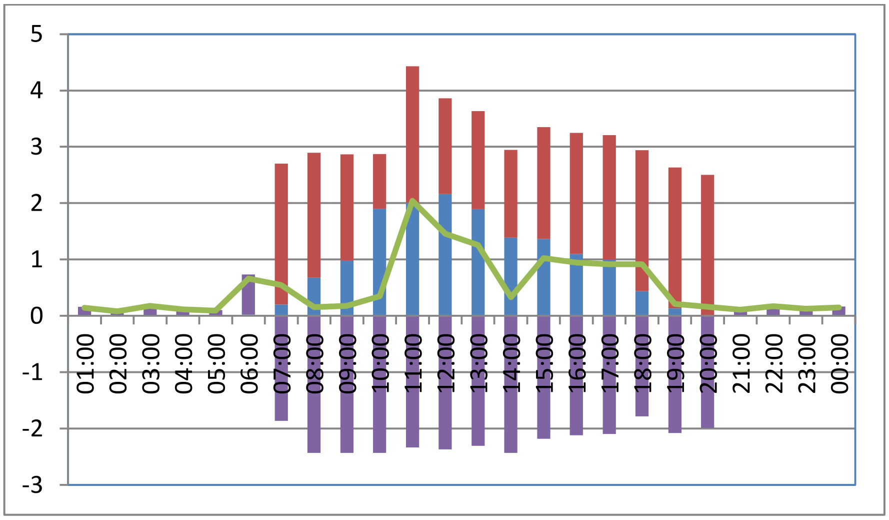

Fig. 10 Hourly energy balance

SYSTEM AUTONOMY AND COST OF ENERGY

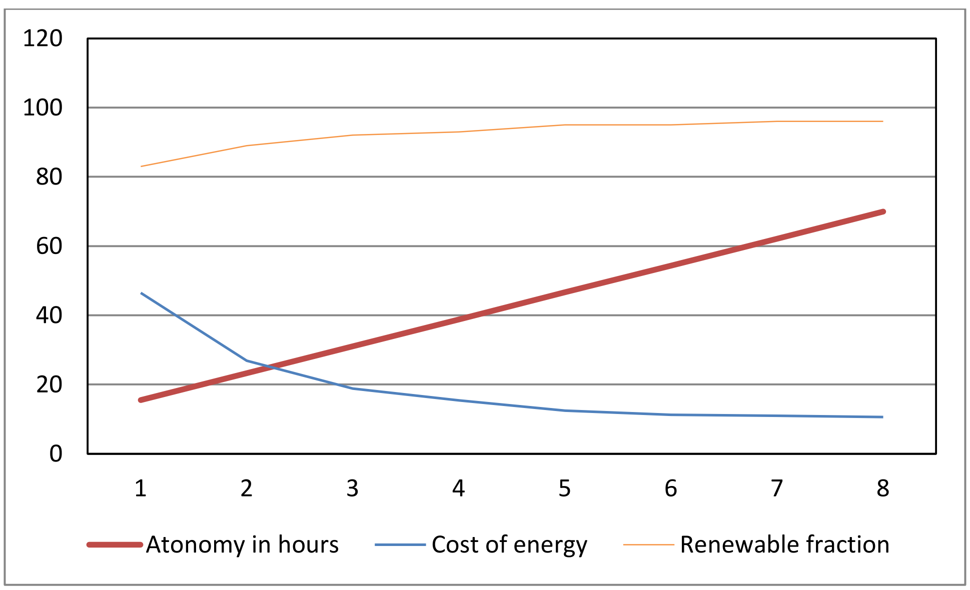

Fig. 11 System Autonomy Analysis

The proposed system is designed for community load facilities, system reliability and power quality play an important role for such a plan. The figure above illustrates three important scheme parameters and relationships. It is observed that with the increase in the capacity of the battery bank, the autonomy of the system increases, the cost decreases sharply and the penetration of renewable energy improves. Estimates made while maintaining supply continuity are set at 100%.

SPIDER GRAPH

Sensitivity findings are displayed using spider charts. It highlights the link between the model's several important components, such as the cost of the PV system, generator, and converter with battery. The cost of energy decreases proportionally to the cost of SPV. Other expenses have an impact on energy price decreases, but only to a modest level.

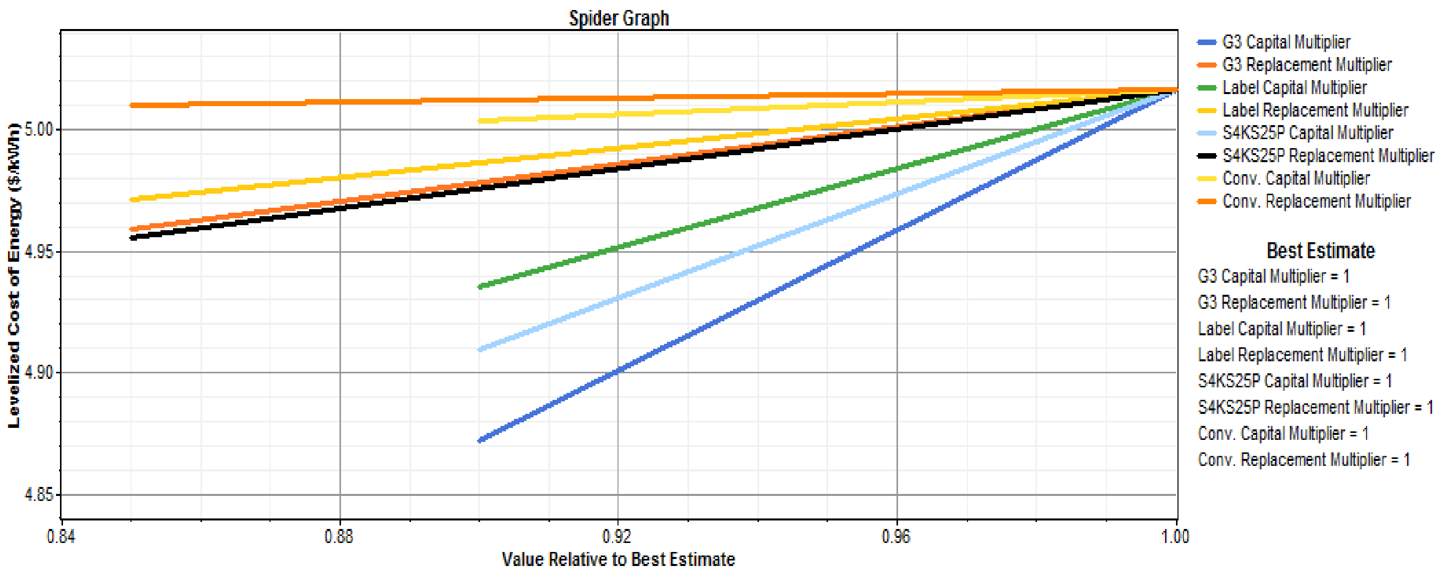

Fig. 12 Spider graph of the system

ECONOMIC ANALYSIS

Table 4.2 Optimized system and its components

PV (kW)	Label (kW)	S4KS25 P	Converter (kW)	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewa ble fraction
3	2.5	9	3	$ 353,438	52,630	$ 1,026,229	15.599	0.89
3	2.5	8	3	$ 347,738	53,105	$ 1,026,594	15.604	0.89
3	2.5	10	3	$ 359,138	52,384	$ 1,028,778	15.637	0.89
3	2.5	9	4	$ 360,338	53,464	$ 1,043,782	15.865	0.89
3	2.5	8	4	$ 354,638	54,740	$ 1,054,394	16.027	0.88
3	2.5	10	4	$ 366,038	53,971	$ 1,055,973	16.051	0.89
3	2.0	9	3	$ 348,381	56,996	$ 1,076,980	16.370	0.89
3	2.5	7	3	$ 342,038	57,742	$ 1,080,172	16.419	0.88
3	2.0	10	3	$ 354,081	57,062	$ 1,083,526	16.470	0.89
3	2.0	8	3	$ 342,681	58,292	$ 1,087,851	16.535	0.89

The 1st fig. shows the overall optimization result of the hybrid system which is generated in the HOMER software. Each row in the table represents a viable system configuration. The four column indicate number or size of each component, the next seven column shows key simulation results, such as capital cost of the system, operating cost, Net present cost, levelized cost of COE, renewable fraction and capacity shortage, diesel used. The optimal configuration is the one having lowest NPC which comprises of 3 kWP PV,9 No of S4KS25P battery, 2.5 kW generator and 3 kW converter. The COE is found to be 15.599/kWh and 89% renewable fraction and no capacity shortage.

Table 4.3 Net present cost of the system

Component	Capital (INR)	Replacement (INR)	O&M (INR)	Fuel (INR)	Salvage (INR)	Total (INR)
PV	243,000	0	0	0	0	243,000
Genartor 1	38,438	0	360,567	277,068	-4,194	671,879
Surrette 4KS25P	51,300	38,165	3,196	0	-10,957	81,704
Converter	20,700	8,637	1,918	0	-1,608	29,647
System	353,438	46,802	365,681	277,068	-16,759	1,026,230

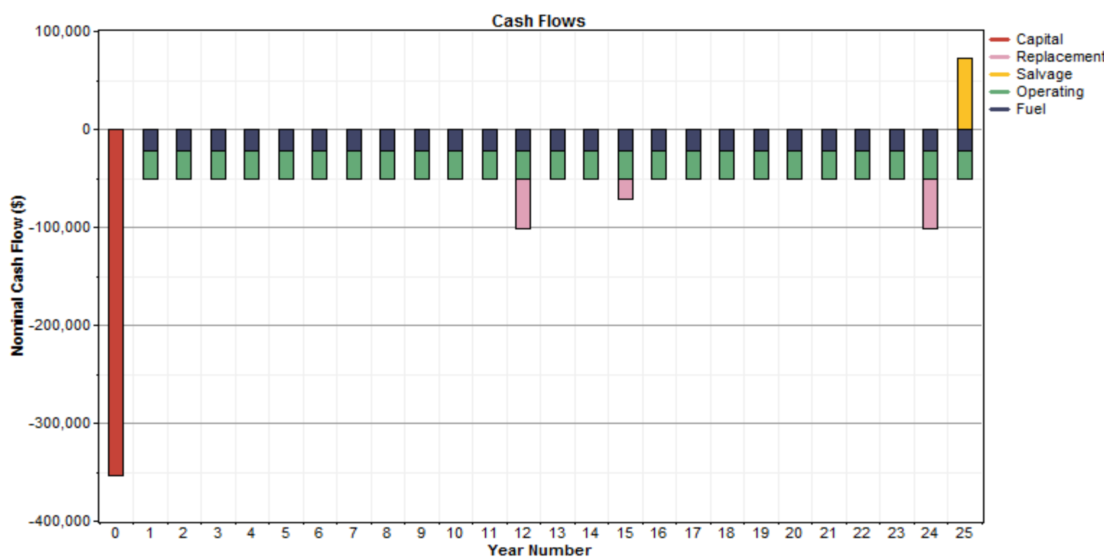

Fig. 13 Cash flow information of the scheme

During the entire life of the project, it needs financial support. The largest part is invested in the first year of the project. The annual expenditure is shown in the figure above. The battery should be replaced every 12 years and the converter should be replaced at the 15th year and the diesel generator should be replaced every 15,000 hours of use.

Table 4.5 system performance analysis

Parameters	Value	Unit
PV array		
Rated capacity	3.00	kW
Mean output	0.66	kW
Mean output	15.7	kWh/d
Capacity factor	21.9	%
Total production	5,743	kWh/year
Minimum output	0.00	kW
Maximum output	3.26	kW
PV penetration	112	%
Hours of operation	4,385	hour/year
Levelized cost	3.31	$/kWh
Label		
Hours of operation	319	hr/yr
Number of starts	20	starts/yr
Operational life	47.0	yr
Capacity factor	3.31	%
Fixed generation cost	109	$/hr
Marginal generation cost	22.1	$/kWh
Electrical production	725	kWh/yr
Mean electrical output	2.27	kW
Min. electrical output	0.750	kW
Max. electrical output	2.50	kW
Fuel consumption	245	L/yr
Specific fuel consumption	0.338	L/kWh
Fuel energy input	2,412	kWh/yr
Mean electrical efficiency	30.1	%
Battery		
Nominal capacity	68.4	kWh
Usable Nominal Capacity	41.0	kWh
Autonomy	69.9	Hr
Lifetime throughput	95,117	kWh
Battery wear cost	0.603	$/kWh
Average energy cost	6.742	$/kWh
Energy in	2,525	kWh/yr
Energy out	2,037	kWh/yr
Storage depletion	19	kWh/yr
Losses	469	kWh/yr
Annual throughput	2,277	kWh/yr
Expected lifetime	12.0	Yr
Inverter		
Capacity	3.00	kW
Mean output	0.56	kW
Minimum output	0.00	kW
Maximum output	2.69	kW
Capacity factor	18.8	%
Hours of operation	8,456	hours/year
Energy in	5,492	kWh/year
Energy out	4,943	kWh/year

Losses	549	kWh/year
Rectifier		
Capacity	3.00	kW
Mean output	0.05	kW
Minimum output	0.00	kW
Maximum output	2.08	kW
Capacity factor	1.7	%
Hours of operation	301	hours/year
Energy in	521	kWh/year
Energy out	443	kWh/year
Losses	78	kWh/year

CONCLUSION

In this study the feasibility of hybrid SPV-diesel generator system is examined for the community load in Leh of Ladkah. The results are showing inspiring. It concludes that with the integration of diesel generator, the power output of the system increases, there capacity shortage restricted to 11%, the cost of energy is 15.59 INR/kWh, which might decrease further with the declining cost of the components. Proposed scheme is also having less emission. The proposed model shows successful integration which can serve the facility with all requisite conditions and through out the year. Hence recommended.

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